

Calibration of Block 4 Translator Path Delays at DSS 14 and CTA 21

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Ground station range delays are currently being performed at 64-m stations in the DSN by use of the "Translator Method." This method requires the absolute calibrations of the delays of the Block 4 Doppler Translator Assembly as well as the cables connecting it to the high-power coupler uplink sampling point and the downlink injection points into S- and X-band masers.

In this article the techniques for calibrating the translator path by means of a portable zero delay device are described. In addition, some translator path data taken at DSS 14, Goldstone, over a period of about one year is presented.

I. Introduction

Ground station delay calibrations are currently being performed by the "Dish-Mounted Zero Delay Device (ZDD) Method" for 26-m antenna Deep Space Stations (DSSs), and the "Translator Method" for 64-m antenna DSS. The Z-corrections required for referring these calibrations to the DSS reference locations have been discussed in Ref. 1 for each of these methods.

The Translator Method requires periodic calibration of the total translator path delay between an uplink sampling point and the downlink signal injection points into S- and X-band masers. The purpose of this article is to describe the procedure

that has been used to calibrate the translator path delay with an R&D Portable ZDD and to present some previous and recent data obtained at the Goldstone Mars Station, DSS 14, and the JPL Compatibility Test Area, CTA 21.

II. Method for Calibrating Translator Delay

The Translator Method involves the sampling of an uplink range-coded transmitter signal from a 54-dB high-power directional coupler. This sampled uplink signal is coherently translated to S- and X-band downlink signals by the Block 4 Doppler Translator installed at all 64-m antenna DSSs. The downlink signals are injected into respective S- and X-band masers via directional couplers.

A simplified block diagram of the translator path between the high-power coupler and maser injection point is depicted in Fig. 1. In the actual installation, the translator path is more complex and includes the following:

- (1) Level Set Attenuator Assembly.
- (2) Uplink Sample Distribution Box.
- (3) Block 4 Doppler Translator Assembly (See Fig. 2).
- (4) Test Signal Control Assembly.
- (5) Noise Box.
- (6) Coaxial to waveguide transitions.
- (7) Interconnecting cables and waveguides.

As explained in Ref. 1, this translator path is in the DSS calibration path, but not in the path when ranging to a spacecraft. Therefore, this delay must be calibrated. The method currently being used to calibrate this path will now be described.

The calibration of the translator path involves two measurements as depicted in Fig. 1. In the first measurement, the Doppler Translator path between the uplink sampling point and the maser injection points are replaced by a portable ZDD and its associated test cables and attenuators. With the ZDD installed, as shown by the dashed lines in Fig. 1, ranging measurements are made and noted on the test data sheet as D_{ZDD} . It should be understood that there is a measured value for S-band and another for X-band but for brevity they will be considered to be those of a single measurement. The second measurement consists of changing the delay path back to the normal translator path with the exception that the ZDD test cables and attenuators are connected in series with the normal translator path cables. The ZDD adjustable attenuators are set to zero and the fixed pads are replaced by pads of lower value to produce received signal levels the same (as nearly as possible) as those of the first measurement. Range measurements are again made and noted on the test data sheet as D'_{XLTR} . The translator path delay can now be determined from subtraction of the first measurement from the second and adding in the delay of the portable ZDD.

Using the equations and terminology proposed in Ref. 1, the procedure can be expressed mathematically as follows:

In the first measurement, the measured range delay with the portable ZDD is

$$D_{ZDD} = \tau_1 + \tau_{ZDD} + \tau_{CABLE} + \tau_2 \quad (1)$$

In the second measurement, the measured range delay of the translator path with ZDD cable is:

$$D'_{XLTR} = \tau_1 + \tau_{XLTR} + \tau_{CABLE} + \tau_2 \quad (2)$$

where

τ_1 = DSS uplink delay from the ranging machine to the high-power coupler sampling point. This delay includes delays of the Block 4 exciter, klystron, filters, and waveguide up to the sampling point.

τ_2 = DSS downlink delay from the downlink maser injection point to the ranging machine. This delay includes delays of the maser, Block 4 receiver and any postamplifiers in the ranging path.

Differencing Eqs. (1) and (2) and rearrangement of terms give

$$\tau_{XLTR} = D'_{XLTR} - D_{ZDD} + \tau_{ZDD} \quad (3)$$

where τ_{ZDD} is the premeasured calibration delay of the portable ZDD without its external cables and is information supplied with the device. It can be seen that the procedure does not require knowledge of τ_{CABLE} which is the delay of the external ZDD cables and pads. If the same cables and equal length pads are common to both measurements, their delays will cancel out in the differencing calculation. This procedure allows the user to use additional lengths of station-available cables if necessary to reach the connection points.

The quantity of interest is τ_{XLTR} , the range delay of the total Block 4 translator path as defined from the high-power coupler to the maser injection point. Equation (3) is for the general case and applies to the procedure for measurement of either the (S, S) and (S, X) translator path delays. For convenience and brevity (S, S) and (S, X) are used throughout this article to denote S- to S-band and S- to X-band translations.

In practice, it is not possible to connect the ZDD cables all the way to the maser injection point.* Therefore, connections are made to the closest available connection point to the maser. In the case of the S-Band Polarization Diversity (SPD) cone at DSS 14, this connection point is a WR 430-to-type N transition on the coupling arm of a 30-dB directional coupler directly in front of the maser. In the case of the X-Band Receive Only (XRO) cone, this connection point is the input

*The maser injection point is currently defined as the midpoint of the cross-guide coupler installed directly in front of the maser.

to the XRO noise box. A correction must therefore be made for the additional lengths of waveguide from the measurement point to the maser injection point. These corrections are calculated from measured physical lengths of waveguide and theoretical group velocity of rectangular waveguide. In the case of the SPD cone, this correction is small (~ 1 ns), but for the XRO cone it is significantly larger (~ 6 ns) because of the noise box path.

The τ_{XLTR} measurement should be performed periodically (semiannually). It is also mandatory that it be performed (1) whenever any new equipment is installed, thus altering the translator path length, and (2) when a subassembly in the translator path be replaced. Absolute configuration control is mandatory. Any change in the translator path will invalidate the measurements.

III. Portable Zero Delay Device

The R&D Portable ZDD that has been used to calibrate Block 4 Translator paths at DSSs 14, 43 (Australia), and 63 (Spain), is shown in Fig. 3. A power splitter at the input permits the uplink signal to simultaneously feed the (S, S) and (S, X) band mixers. The local oscillator (LO) drive for the portable ZDD is supplied by the Block 4 Doppler Translator Assembly. The portable ZDD is basically a miniature Block 4 Translator without remotely controllable attenuators, filters, internal LO drives, etc. Therefore, its delay is small (typically less than 2 ns) and can be calibrated precisely in the laboratory with best available state-of-the-art techniques.

The portable ZDD contains a mixer assembly whose absolute delay is difficult to calibrate. Although different techniques were tried, the best result was obtained from a technique where two identical assemblies were cascaded back-to-back. The total measured delay is divided by two. The total present accuracy of the portable ZDD is estimated to be ± 1.5 ns (3σ).

The state-of-the-art of mixer delay measurement is currently not sufficiently advanced, so it is not clear whether the present accuracy of ZDD calibrations can be improved further without considerable development effort and cost.

Tests were made on the portable ZDD by use of a demonstration model "Microwave Link Analyzer" manufactured by Hewlett-Packard. Absolute delays of translators cannot be calibrated by the Link Analyzer, but relative delay changes can be calibrated to better than ± 1.0 ns. The tests showed that the portable ZDD delays were constant, with

frequency to within ± 1.0 ns over a 50-MHz bandwidth at the center transmit and S and X receive frequencies for the DSN.

The R&D ZDD shown in Fig. 3 has been used in the past to calibrate translator paths for all 64-m antenna DSS. In the future, 64-m stations will be supplied with their own calibrated portable ZDD.

IV. Test Results

A. Measurement of D_{ZDD} and D'_{XLTR}

To illustrate the measurement technique described in the previous section, some test data of D_{ZDD} and D'_{XLTR} at DSS 14 are shown in Figs. 4 through 7. The data were taken at different time periods and taken at several frequencies. These frequencies are indicated by transmitter voltage controlled oscillator (VCO) channel numbers. The relationship of channel number to microwave transmit (uplink) and receive (downlink) S- and X-band frequencies may be seen in Table 1.

Most of the slow upward trend seen in D_{ZDD} and D'_{XLTR} as a function of channel number is attributed to changes of klystron, exciter, maser, and receiver delays as a function of frequency. Since most of the delay changes with frequency are common to both measurements, they should cancel out in the differencing calculations. The individual amounts that various mentioned assemblies contribute to delay changes with frequency have been investigated and will be reported upon in a future DSN Progress Report.

B. Calibration of τ_{XLTR}

Figure 8 shows the calibrated translator delays τ_{XLTR} as determined from the D_{ZDD} and D'_{XLTR} measurements and use of Eq. (3). The calibrations done at different times were all performed using the same R&D portable ZDD shown in Fig. 3. Slight modifications to the portable ZDD were made at different times, but these have been accounted for in the updated values of τ_{ZDD} furnished with the device each time.

Figures 8a and 8b, respectively, show τ_{XLTR} values for the (S, S)-band path and (S, X)-band path at DSS 14. The measurements were made on October 23, 1975, May 16, 1976, and December 10, 1976.

It can be seen in Fig. 8a that the (S, S) translator delay values agree closely for October 23, 1975, and December 10, 1976, but the delay value for May 16, 1976, does not agree well. In the May 16 data, however, there is a cyclical variation in both the (S, S) and (S, X) data that indicates that there

could have been a leakage problem on the uplink similar to a multipath effect. Some tests and analysis of data made to explain these data are discussed in Part 5 of this article.

Figure 8b (S, X) delays on October 23, 1975, disagree with the other results by about 10 ns. The December 10 data showed that most of the cyclic variation seen on May 16 had disappeared. It is of interest to note that the (S, X) delays do not show an upward trend with frequency as do the (S, S) delays in Fig. 8a.

Figure 8c shows test data taken of a similar Block 4 Doppler Translator Assembly at CTA 21. The data show some cyclic variation, but some of this is attributed to measurement noise and nonrepeatability. There are two 13-pole filters and significant lengths of cable, and a number of components (such as switches and remotely controllable attenuators) to explain the large delays of about 80 to 90 ns. The filters are reasonably broadband and hence do not cause a significant variation of delay with frequency.

V. Analysis of the Leakage Problem

Tests were subsequently performed at DSS 14 during November and December, 1976, to pinpoint the cause of the large cyclic variations in translator delays seen on May 16, 1976. One test performed was a multipath test, which involved moving the subreflector through 6 inches of travel and observing variations in ground station delay. The test results showed less than 2 ns peak-to-peak (p-p) change on either (S, S) or (S, X) range delays. The 2 ns p-p was about the same as the noise on the measurement and repeatability. Since the Block 4 translator method uses directional couplers to obtain the uplink sample and couplers to inject downlink signals, the DSS calibrations by this method are significantly isolated from multiple-reflected signals that radiate back into the horn from the external antenna structure. Most portions of the uplink signals that reflect back into the horn are absorbed by the klystron. Due to the high directivity of the sampling coupler, very little reflection gets coupled back into the translator.

Analysis made of the May 16 data shows a possible explanation of the cyclic variations. Referring to measurements of D_{ZDD} and D'_{XLTR} values shown in Figs. 4 through 7, it can be seen that the cyclic variation appears only on the measurements of D_{ZDD} made on May 16, 1976. This type of behavior can be due to a leakage problem. Because of the similarity of the (S, S) and (S, X) data for D_{ZDD} , it is probable that the leakage was on the uplink path only. A loose connection probably occurred between the short 8-ft. uplink cable (supplied with the ZDD) and the high-power coupler.

VI. Evaluation of the Calibration Method and Results

The Translator Method was proposed initially as an interim solution to meet the immediate requirement by the Viking Project for a 5-m overall range accuracy. Serious calibration errors on 64-m antennas through the airpath were known to exist due to multipath and were reported in Ref. 2. The translator method was proposed as a satisfactory and economical interim solution for 64-m antenna DSS delay calibrations.

Experimental work is progressing on evaluating the absolute accuracy of this method. There are several known problems and disadvantages of this method. Some of the problems are:

- (1) The translator path delay is large and varies with frequency. The number of subassemblies (See Part 2 of this article) in the translator path make it difficult to keep it from being frequency and temperature sensitive.
- (2) Rigid configuration control and monitoring is required. A DSS must report when a component is replaced in the translator path or if any new cable is installed and recalibration is necessary.
- (3) The DSS 14 S-band translator path is different from that of DSS 43 and 63 due to a nonstandard SPD cone and noise box. A significant difference in the DSS 14 (S, S) translator path delay leads to suspicion concerning the validity of measurement accuracy.
- (4) The sampling and injection points are too far from the feed horn.
- (5) There is a slight difference in uplink delay through the "Level Set Attenuator Assembly" in the translator path for the 400-kW and 20-kW klystron operation modes.
- (6) The actual translator delay measurement can be made (conveniently) only up to the last coaxial connection point. In the XRO cone, the actual delay measurement stops at the input to the XRO noise box.
- (7) Leakage problems can occur. The measurements require special care by station personnel to use good laboratory techniques such as putting terminations on unused ports and cables and making sure that all connections are tight. Due to the stiffness of RG 252 cable, disconnection of this cable sometimes leads to loosening of other component connections in the system.
- (8) Some drift in system delay can occur between measurements of D_{ZDD} and D'_{XLTR} producing an error. This drift can be of the order of ± 5 ns.

Some recommendations for improving quality of data from this method are:

- (1) Repeat initial measurements to check for drift.
- (2) Go back to standard translator configuration without the ZDD cables and measure D_{XLTR} . The difference between D'_{XLTR} and D_{XLTR} should be the total ZDD cable delay and agree with calculable values to within ± 2 ns.

VII. Summary and Conclusions

The Translator path delay Measurement Technique has been described. Some data taken at DSS 14 pointed up some measurement problems, but in general it can be concluded that the translator path delay is probably stable with time to within ± 7 ns. The (S, S) delay varies about 12 ns with frequency from channel 5 to channel 29. The cause of this frequency variation

is not presently understood. Measurements made at CTA 21 showed that the Doppler Translator Assembly itself does not have significant variation of delay with frequency. Some similar measurements should be done at DSS 43 and DSS 63 to see if this frequency variation of translator path delays occurs at other 64-m stations.

Although the Block 4 Translator method has many problems and disadvantages, it is superior in accuracy to the airpath method, which has large multipath errors. It should be pointed out that multipath errors are also frequency sensitive. The "Translator Method" could be improved if there were a separate translator (simpler than the Block 4 Translator), and shorter paths and connection points dedicated specifically to ranging calibrations. A proposal for future consideration is to use a permanently installed portable ZDD, such as described in this article.

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References

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2. *A Collection of Articles on S/X-Band Experiment Zero Delay Ranging Tests*, Technical Memorandum 33-747, Vol. 1, pp. 114-126, edited by T. Y. Otoshi, Jet Propulsion Laboratory, Pasadena, Calif., Nov. 1975.

Table 1. Transmitter VCO channel vs. transmit and receive frequencies ^a

Channel number	S-Band transmit frequency, MHz	S-band receive frequency, MHz	X-band receive frequency, MHz
5	2110.243	2291.667	8402.778
10	2111.948	2293.519	8409.568
15	2113.654	2295.370	8416.358
20	2115.359	2297.222	8423.148
25	2117.064	2299.074	8429.938
30	2118.769	2300.926	8436.728

^aThe channel number versus transmit/receive frequency curve is linear.

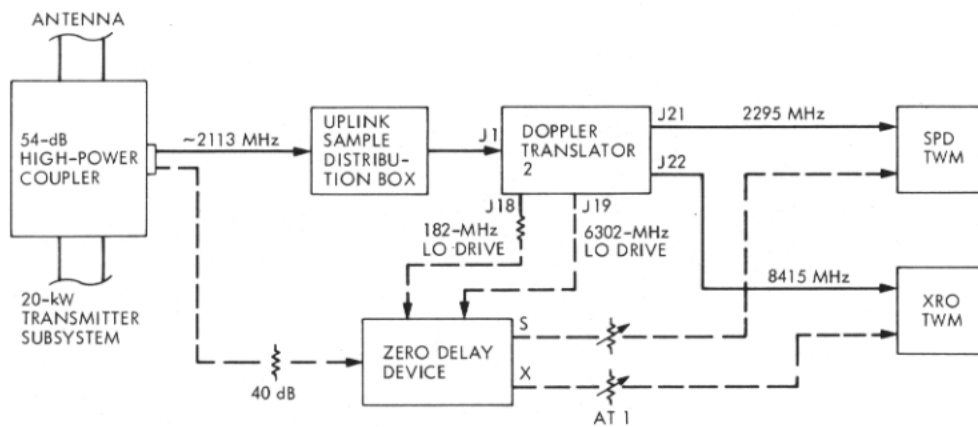


Fig. 1. Configuration for translator path delay calibration

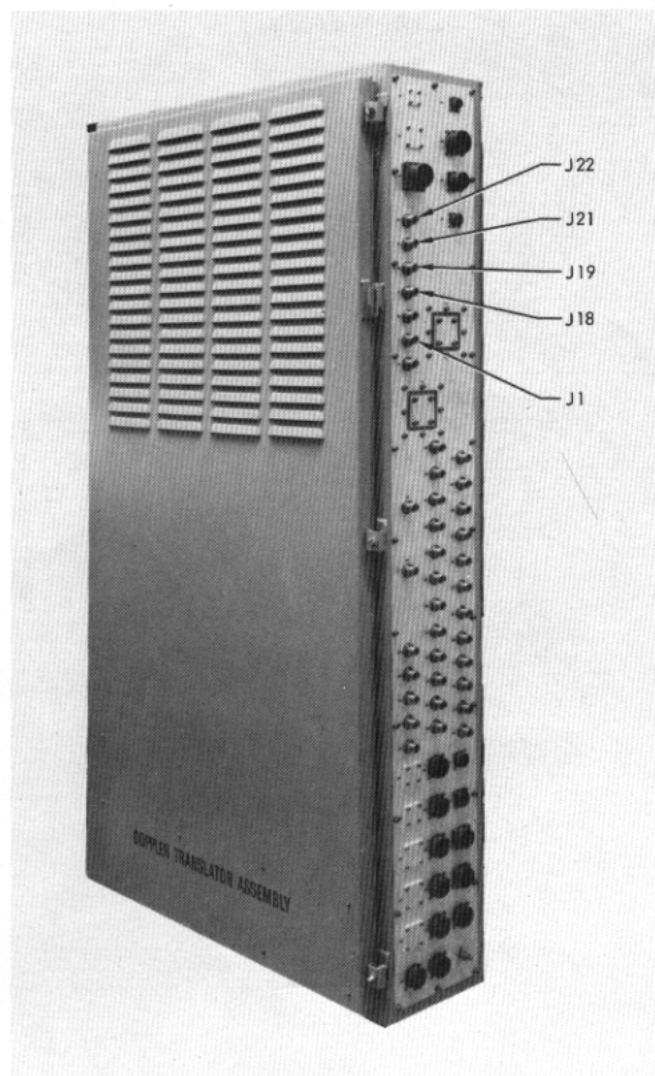


Fig. 2. Block 4 Doppler Translator Assembly (port numbers identify connection points shown in Fig. 1)

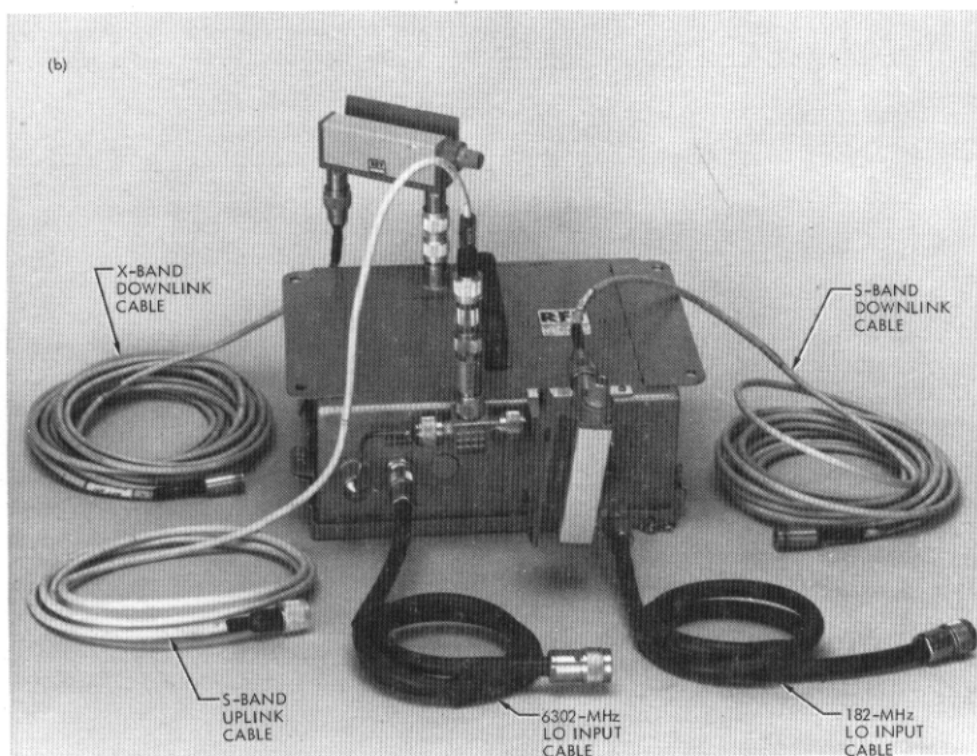


Fig. 3. R&D portable zero delay device : (a) without external test cables and attenuators, (b) with external test cables and attenuators

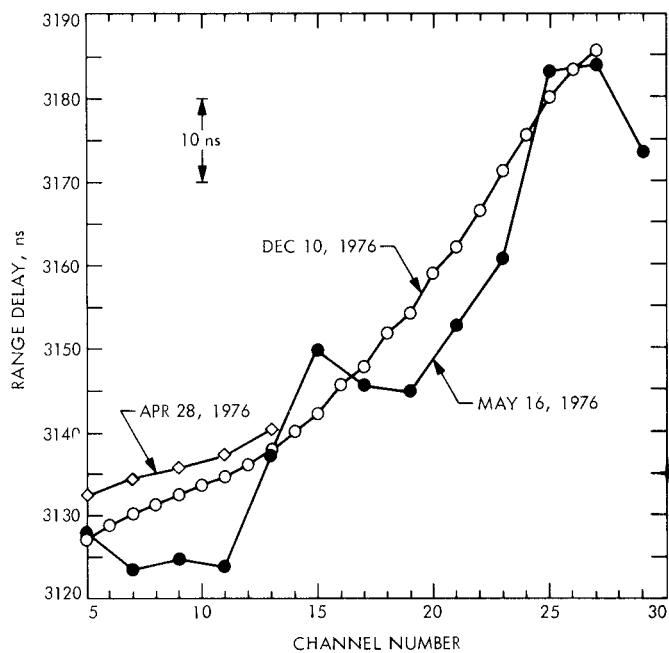


Fig. 4. Measurements of D_{ZDD} versus frequency at DSS 14 for the S-band uplink and S-band downlink path

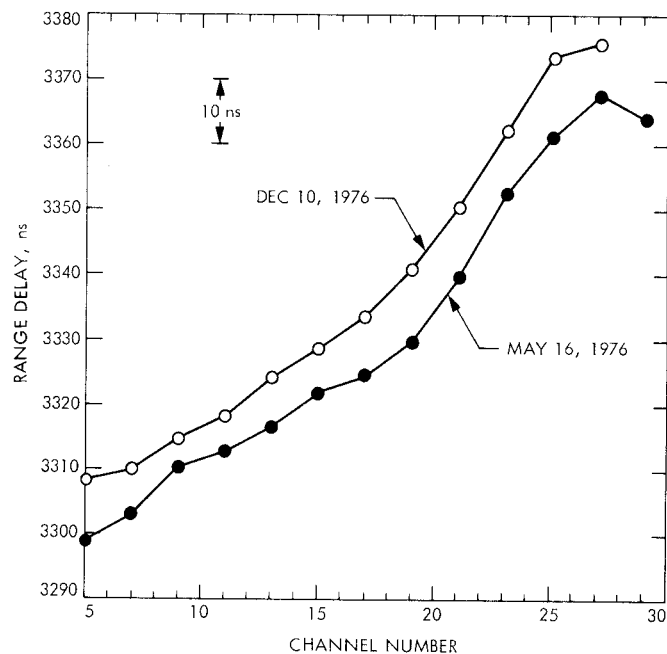


Fig. 6. Measurements of D'_{XLTR} versus frequency at DSS 14 for the S-band uplink and S-band downlink path

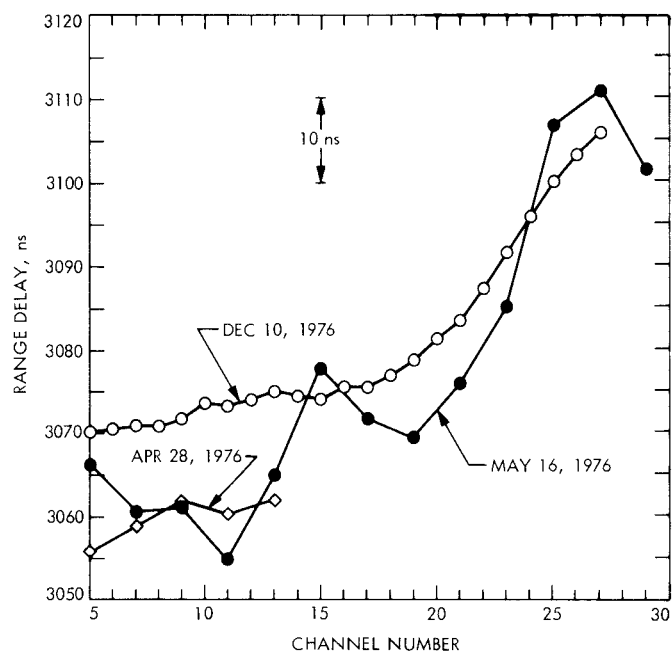


Fig. 5. Measurements of D_{ZDD} versus frequency at DSS 14 for the S-band uplink and X-band downlink path

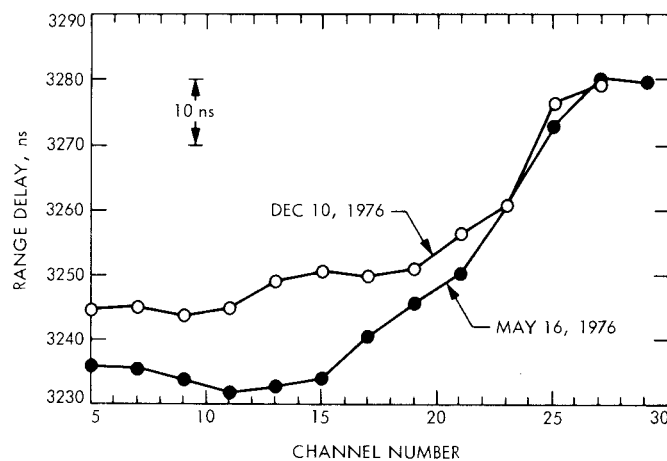


Fig. 7. Measurements of D'_{XLTR} versus frequency at DSS 14 for the S-band uplink and X-band downlink path

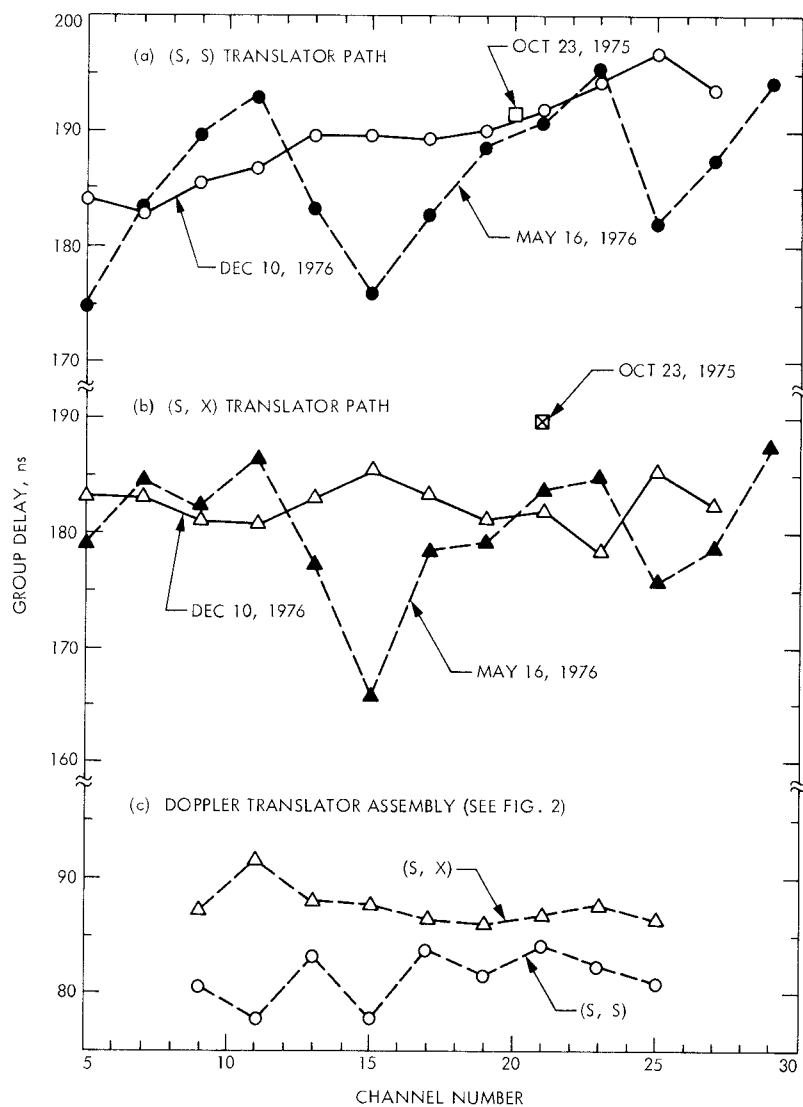


Fig. 8. Block 4 translator delay measurements: (a) (S, S) τ_{XLTR} values for DSS 14, (b) (S, X) τ_{XLTR} values for DSS 14, (c) Doppler Translator Assembly (Fig. 2) delay measured at CTA 21 on October 11, 1976